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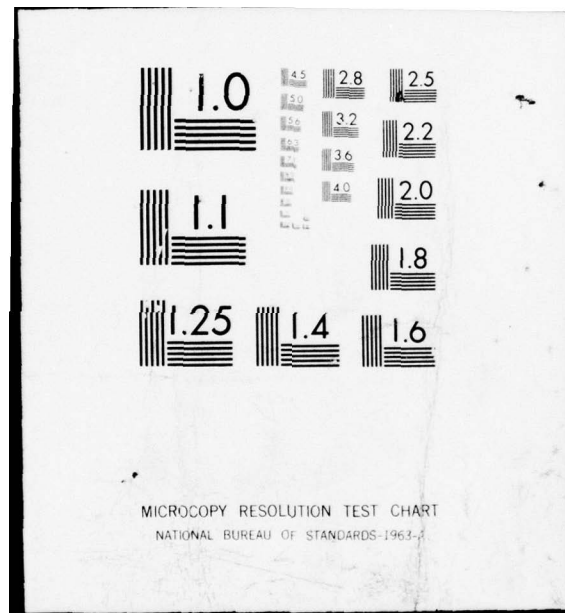
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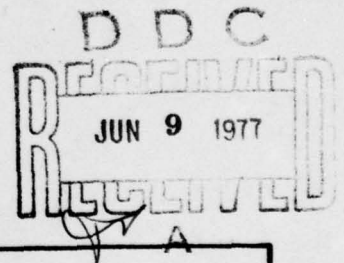
VOLUME I of III

by

Duane O. Gustad

January 1977

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Manufacturing Technology Directorate



U.S. ARMY ARMAMENT COMMAND
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20. ABSTRACT (Cont)

temperature, parting to mult length and forging can be accomplished as a completely integrated, synchronized and automatic operation.

Hot shearing studies were conducted on the 105 mm M1 and 155 mm M107 projectiles. Hot shearing was determined to be a completely satisfactory method of billet separation for projectile manufacture. Benefits which can be achieved from use of hot sheared mults are derived from reduced material handling, reduced material waste, reduced operating cost and improved projectile cavity surface finish.

Hot flame cutting was determined to not be a successful process for parting of mults for projectile manufacture. Slag and molten metal caused problems in subsequent forging operation.

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I. OBJECTIVE

The objective of this project was to establish a new, improved production technique for separation of heated billet stock which, after parting, would be immediately forged into a projectile shape.

II. INTRODUCTION

The billet parting concept investigated under this project involves heating 20 to 24 foot billet lengths of steel to forging temperature of approximately 2200°F and hot shearing to required forging (mult) length; after which, hot sheared mults move directly to the forging press. Using this concept, heating, separation and forging of the billet stock is an integrated, completely automatic operation.

The four existing methods of billet separation either currently or previously used in projectile manufacture are: Nick & Break, Cold Shearing, Flame Cutting and Sawing. A tabulation of undesirable characteristics associated with current separation processes compared to hot shearing is shown in Table 1. Inefficiencies which can be attributed to each of the current methods are:

Excessive Material Handling - All current separation methods are done cold. This means that individual mults must be transported from the separation operation to the hot forge furnace, placed individually in the furnace, removed individually from the furnace and transported to the forge press.

Material Waste - The worst process with respect to material waste is the nick and break process. This also happens to be the process used most prevalently in projectile forging operations. Selection of billet parting processes and equipment in existing plants was done when material costs were low; therefore, material waste was not as great a concern. Current high material costs dictate that greater attention be given to material savings. Due to the angular breaks experienced with the nick and break process, one can never be certain just what the weight of the broken mult will be. To compensate for this, mults must be broken extra long to assure the broken mult will not fall below the weight required to make an acceptable projectile. With both sawing and flame cutting, there is a kerf loss which results in material waste.

High Operating Cost - High operation costs are associated with both sawing and the flame cutting processes; sawing because of the saw blade cost and flame cutting because of gas and oxygen cost. Recently, steel companies have started charging an extra of \$28 per ton to supply some grades and sizes of steel in a suitable condition for cold shearing. The addition of this extra material charge changes cold shearing from a relatively inexpensive process to a very costly operation.

TABLE 1. Comparison of Current Billet Separation Techniques with Hot Shearing

Separation Process	Excessive Material Handling	Material Waste	High Operating Cost	Surface Irregularities	Scale
NICK & BREAK	X	X		X	X
SAWING	X	X	X		X
COLD SHEARING	X				X
FLAME CUTTING	X	X	X	X	X
HOT SHEARING					

Surface Irregularities - Defective projectile cavities resulting from surface irregularities on the parted surface often occur when using both the nick and break and flame cutting processes. The nick and break process can leave slivers of metal on the parted face which end up as laminations in the projectile cavity. Provided such defects are not of any significant depth, projectiles containing these defects are currently salvaged by grinding out the defect. This involves a costly labor operation. Flame cutting, if properly controlled, is much less of a problem in this area; however, when out of control surface irregularities result from this process also.

Scale - Scale is a problem associated with all of the existing parting processes. Mults are currently parted after which they are placed in a furnace for heating to forging temperature. During this period of heating, surfaces of the mults are exposed to the furnace atmosphere and become scaled. Since one end of the mult becomes the inside surface of the projectile after forging, any scale present on the end of the mult becomes imbedded in the projectile cavity surface resulting in a very poor quality surface condition.

The problem areas, inefficiency and high costs associated with existing billet separation techniques dictated that a new method of billet separation be investigated. The hot shear concept of billet separation offered the greatest potential for overcoming inefficiencies associated with existing processes and was also a process that could be implemented as part of an integrated, completely synchronized and automated forging line.

In addition to the above benefits, hot shearing appeared to be a process which would be adaptable to various steel grades and material conditions. Billet parting techniques such as sawing, cold shearing and flame cutting are limited to low and medium carbon grades of steel. In some instances preheating or special conditioning of the material is required prior to parting. Newer munitions are being made from high fragmentation and alloy grades of steel where problems could be anticipated in billet parting using some of the current techniques. Fragmentation materials such as HFI would be susceptible to cracking if parted by either shearing or flame cutting and sawing of this high carbon, hard material would be prohibitive based on cost considerations. Since in the hot shearing process, the material is heated to forging temperature prior to parting, the hardness, strength and brittleness of these materials would not present any problem when using the hot shear concept of billet separation.

III. SUMMARY

Hot shearing studies were conducted on the 105 mm M1 and 155 mm M107 projectiles at the National Presto Industries Inc., Eau Claire, Wisconsin and Twin Cities Army Ammunition Plant, (TCAAP) New Brighton, Minnesota respectively. Performing the studies at these two facilities permitted evaluation of hot sheared mults using both the hot cup-cold draw (National Presto) and hot forge (TCAAP) processes of projectile manufacture.

A hot shear press and associated tooling was purchased from Rheinstahl Wagner Company in Dortmund, Germany and installed at National Presto. Using this piece of equipment, an engineering study was conducted to establish process parameters for hot shearing of billet stock in steel grades 1018, 1046 and HFl such that the parted stock could be subsequently processed into a defect-free projectile. Parameters investigated during the study included billet temperature, shear blade clearance and shear speed.

After establishing optimum hot shear process parameters, a quantity of 1000 mults were hot sheared at National Presto and subsequently processed into 105 mm M1 projectiles using Presto's standard hot cup-cold draw process. This process is recognized as requiring a higher quality starting mult than the hot forge process of manufacture and therefore, was considered to be a severe test of the adequacy of the hot shear method of billet separation. Visual and magnetic particle inspections were performed on each of these projectiles after forging and after the nosing operation. No defects were found that could be related to the fact these projectiles were processed from hot sheared mults. In terms of tolerance on length, weight control and overall quality of parted surface, hot sheared mults equaled or exceeded the results currently achieved at National Presto using the band saw method of billet separation. This was a significant finding because sawing up to this time had been considered to be the most exact method of billet separation and yield the highest quality mults.

Hot shear studies on the 155 mm M107 projectile were conducted at TCAAP using mults hot sheared at Caterpillar Tractor Company in Peoria, Illinois. Approximately 100 tons of steel was hot sheared into mult lengths at Caterpillar and subsequently shipped to TCAAP where a total of 1144 hot sheared mults were successfully processed into 155 mm M107 projectiles using the hot forge process of manufacture. One of the significant findings at TCAAP was the noted improvement in projectile cavities when using hot sheared mults. Nick and break is the standard billet separation process used at TCAAP. This process results in an irregularly broken mult surface and repair of projectile cavities by grinding is often required. Based on test results when processing hot

sheared mults, it appears cavity defects and resulting grinding to remove these defects can be significantly reduced when using hot sheared mults.

A secondary study was conducted at National Presto to determine the feasibility of hot flame cutting mults. The purpose of this study was to determine if hot flame cutting would be an acceptable method of parting the last mult in a billet length from the discard. Slag clinging to the bottom edge of the mult after flame cutting presented a problem and this method of billet separation was determined to be unacceptable for projectile manufacture. Through use of an outboard support and clamping of the mult while hot shearing, no problem of separating the last mult from the discard will be encountered and an auxiliary method of separating this last piece will not be required.

IV. CONCLUSIONS

1. Hot shearing produces high quality mults suitable for processing into artillery projectile bodies by both the hot cup-cold draw process and the hot forge process of manufacture.
2. In terms of tolerance on length, weight control, perpendicularity and overall quality of parted surface, hot sheared mults equaled or exceeded the results currently achieved at National Presto using the band saw method of separation.
3. Hot shearing produces a clean, scale-free mult end surface condition which resulted in a significant improvement in the quality of hot forged projectile cavities when compared with projectiles forged using nicked and broken mults.
4. The temperature ranges within which high quality hot sheared mult ends were obtained for the three grades of steel hot sheared at National Presto during this study were:

AISI 1018 - 1800°F to 2250°F

AISI 1046 - 1700°F to 2150°F

HFI - 1800°F to 2000°F

5. Optimum shear blade clearance consistent with high quality sheared ends was determined to be .020".
6. Shear blade stroke speed did not have a significant effect on sheared mult end condition within the range of shear speeds available (144"/minute to 200"/minute).
7. Steel grades HFI and 1046 can be hot sheared with equally satisfactory results as 1018 grade steel.
8. Benefits achieved from hot shearing when compared to other methods of billet separation are related to (1) reduced material handling (2) material savings resulting from use of lighter, more uniform weight mults (3) lower operating costs (4) reduced scrap losses at both the billet parting and forging operations and (5) greater efficiency resulting from an integrated heating, billet separation concept.
9. Cost savings for hot shearing compared to the nick and break process of \$0.45 and \$0.97 have been estimated for the 105 mm M1 and 155 mm M483 projectile respectively.

10. Use of a cut-to-weight system in conjunction with hot shearing of mulds provides material weight savings up to .85 and 1.03 pounds/shell for the 105 mm M1 and 155 mm M107 respectively. This material savings is directly attributable to the cut-to-weight system and is in addition to material savings resulting from being able to hold a close length tolerance on hot sheared mulds.

11. A potential disadvantage of hot shearing is that the hot shear is an integral part of the forge line; hence, production off the forge press is directly dependent on operation of the hot shear press. However, hot shear equipment currently in use in this type application has been found to be very reliable and no significant forge line down time directly related to down time of the hot shear has been experienced.

12. Use of a hold down mechanism on both the inboard and outboard side of the hot shear press is considered to be the best technique to minimize material losses when separating the discard in each billet length from the last mlt in the billet length.

13. When purchasing hot shear equipment, it is important that the hot shear press be purchased as part of a complete furnace-hot shear press system with one contractor responsible for the entire system. This is necessary because the entire line from unscrambling table up to delivery of the hot sheared and descaled mulds to the forging press must operate as a fully integrated system with all units synchronized with each other for automatic operation.

14. The quality of hot flame cut mulds is not acceptable for projectile forging applications due to slag which clings to the bottom edge of the mlt and prevents production of acceptable forgings on a reliable production basis.

V. RECOMMENDATIONS

1. Hot shearing should be implemented into the new manufacturing facilities being planned for production of the 105 mm M1 and 155 mm M483 projectiles.

2. Hot shearing should be implemented into future new or modernized metal parts facilities when new forging furnaces are being purchased so that hot shearing can be integrated into the forging line.

3. Hot shear equipment should be purchased as part of a furnace - hot shear press system with one equipment supplier responsible for the entire system to include unscrambling table, hot shear press, descaler and all auxillary material handling equipment.

VI. BACKGROUND

The hot shearing concept of billet separation investigated under this project is not new. One example of this type of production which has been in use for more than 20 years is the forging of hexagon nut blanks and similar configurations on horizontal multi-station progressive hotformers. Teamed with automatic bar heaters, these hotformers combine feeding, heating and forging operations into a fully automatic production system starting with bundles of mill-length bars at one end of the line and ejecting pierced precision forgings at the other end of the line. In operation, heated bars are continuously fed to the hot-former, hot sheared to length and shaped in three consecutive forging operations. As a rule, the first station is used for preforming, the second for finish forming and the third for piercing. A finished forging is ejected at each stroke. However, machines of this general type are limited to a maximum weight of the forging of about six pounds.

A more recent commercial installation using this same general concept for larger bar sizes became operational in 1969. This forging line uses a vertical press with side mounted hot shear capable of shearing up to 6" diameter round bars. This forging line is part of a complete production facility for manufacture of railway bearing races which weigh up to 50 pounds. Operational characteristics of this line are as follows. Steel bars are loaded onto an inclined bed so that feeding of the bars into the induction heating unit is performed automatically. The induction heating units which are capable of heating 10,500 pounds per hour consist of seven induction coils with motor driven support rolls between each coil box. The forging temperature of approximately 2300°F is achieved in less than five minutes. A mechanical crank type shear which is an integral part of the forging press is located at the exit end of the furnace. As the bar exits from the induction furnace, it moves up against an adjustable stop on the press which establishes the mult length for shearing. The feed table, induction furnace, hot shear and forging press are all synchronized through one control panel for completely automatic operation from feeding of the bar stock to finished forging.

Review of the forging operations described above indicated a high probability of success in adapting the hot shear concept to projectile forging; however, there were questions that needed to be resolved before the concept could be implemented into a projectile forging line. These questions were related to the following areas:

1. Most projectiles have "as forged" cavities in the finished item. Would a hot sheared mult surface be of high enough quality to preclude defects in the projectile cavity originating from the hot sheared surface?

2. Would pull down (deformation) at the edge of the mult during hot shearing cause problems in the subsequent forging operation. Potential problems were eccentricity in the forging or difficulty in getting the mult into the forging die?

3. Would any problems be experienced in hot shearing round cornered square material as opposed to the round material that had been hot sheared up to this time?

4. What variations in shear quality would be experienced in hot shearing the various grades of steel used in projectile manufacture?

In addition to obtaining answers to the above questions, optimization of hot shearing process parameters and controls and specific information on weight and length tolerances achievable by hot shearing were required prior to recommending hot shearing for implementation into projectile forging facilities. It was toward this end that investigations conducted under this project were performed.

VII. STUDY

A. Procurement of Hot Shear Press

At the time this study was initiated there was only one U.S. manufacturer using hot shearing of mults for forging application in the steel stock sizes of interest. This manufacturer's process used round steel starting stock as opposed to round cornered square stock which was of interest for artillery projectile manufacture. Also, due to production requirements, this manufacturer was not willing to do any trial shearing of government furnished material. Based on these considerations, the decision was made to procure a hot shear press, install it at a projectile manufacturing facility and conduct a study of the hot shear process.

Numerous U.S. builders of shearing equipment were contacted to determine their interest and capability to furnish a hot shear press for the intended application. Responses from these companies indicated that satisfactory hot shear equipment of the size and design required for the intended useage had not been manufactured in the United States. The hot shear equipment built in this country is primarily used in the steel industry for cropping ends of bar or billet lengths where the quality of the parted surfaces is of little consideration. Since U.S. manufacturers of hot shear equipment had not had to concern themselves with the quality of hot sheared surfaces, the technology and basic principles underlying the design of hot shear equipment for the intended application had not been developed in this country.

As discussed earlier, the use of the hot shear approach to billet separation for forging applications in the proposed billet sizes is a relatively new concept. Currently, U.S. installations using this forging concept are using hot shear equipment built by Rheinstahl Wagner Company in Dortmund, West Germany. The hot shear built by Rheinstahl Wagner was designed specifically to be used in connection with an integrated forging operation; whereby, the heating of billet lengths for forging, hot shearing and subsequent forging are performed as a continuous integral operation. Because of this intended useage, the hot shear has design features which minimize distortion and smearing associated with conventional steel mill hot shear equipment.

For the purposes of this study it was considered essential that a hot shear be used that had been designed and manufactured by a company with specific experience and knowledge of hot shearing of billets for forging applications. To attempt to conduct this study with anything less than a proven piece of equipment could have meant failure of the project and inability to determine the parameters and controls necessary for successful performance of the hot shear. Since this equipment was not available in the U.S., the hot shear press was procured from Rheinstahl Wagner.

Specific performance requirements of the Rheinstahl Wagner hot shear which were considered essential for hot shearing of mullets to be used in forging of projectiles were: (1) a minimum amount of deformation during the shearing process and (2) a smooth, defect-free hot sheared surface. Any defects present on the hot sheared surface would end up in the cavity of the forged projectile. Since the cavity surface is not machined on many types of projectiles, such a defect could not be permitted for safety reasons.

B. Hot Shear Study on 105 mm M1 at National Presto

The Rheinstahl Wagner hot shear press was procured and installed at National Presto Inc., Eau Claire, WI, for performance of an engineering study of the hot shear concept of billet separation. This study was conducted in four phases as follows:

Phase I - Design and modify equipment as required and make equipment set-up necessary for the study.

Phase II - Experimentally establish parameters of hot shearing which provide optimum quality sheared ends.

Phase III - Forge 1000 projectiles using the hot cup-cold draw process and 1018 steel with the equipment set-up and process parameters established in Phases I & II. All 1000 projectiles to be magnetic particle inspected after forging and again after nosing.

Phase IV - Perform hot shear studies on 1046 and HFI grades of steel to compare hot shearing characteristics with 1018 steel.

A complete report on the hot shear study conducted at National Presto is contained in Volume II. A summary of this work is presented below.

The Rheinstahl Wagner hot shear press was procured and installed at National Presto Inc., Eau Clair, WI, for preformance of an engineering study of the hot shear concept of billet separation. Performance characteristics of the hot shear press are included in Appendix A. The equipment required for the study, in addition to the hot shear press, included a bar conveyor, a bar index mechanism and an induction type bar heater. With the exception of the hot shear press, all of this equipment was built at National Presto and installed in a manner such that the equipment functioned as an integrated bar heater, hot shear press system.

Parameters investigated during the study included billet temperature, shear blade clearance and shear speed. Table 2 graphically depicts all combinations of these variables investigated during this study on 1018 steel and the results achieved, and is the basis for the data given under conclusions on page 8 of this report.

A quantity of 1000 projectiles were successfully forged from hot sheared mults without difficulty. Visual and magnetic particle inspections performed on the forgings and nosed shells revealed no defects that were related to the hot shearing process. Projectile cavity finish was considered equal to that obtained in normal production using saw cut mults.

A photograph of a typical mult hot sheared at National Presto is shown in Figure 1. This photograph shows the good surface quality and minimum corner deformation achieved in hot shearing 105 mm M1 mults. Weight and dimensional tolerances achieved on hot sheared mults processed during this phase are shown in Table 7, page 23.

The temperature effect on hot shearing 1046 and HFI grades of steel was investigated using the stroke, speed and blade clearance setting established as optimum for 1018 steel. In addition, blade clearance just above and below the manufacturer's recommended minimum setting of .020" was examined for 1046 steel. Both grades of steel were successfully hot sheared. Table 3 graphically depicts all combinations of variables investigated in this phase and the results achieved.

TABLE 2. Chart Depicting Mult Quality for Various Process Parameters Investigated for 1018 Steel.

Blade Clearance Blade Speed*	Temperature (°F)															
	2250	2200	2150	2050	2025	2000	1950	1925	1900	1875	1850	1825	1800	1775	1750	1725
.037" Min.						G	G		G		G	G			G	G
.037" Max.					G	G	G	G			G		G		P	
.028" Min.						G	G		G		G	G	G			
.028" Max.						G	G	G			G		G		G	P
.020" Min.						G	G		G				G			
.020" Max.						G	G	G					G	G	G	P
.015" Min.						G	G						G		G	
.015" Max.						G	G						G		G	P

*Blade Speed
Minimum = 144" per minute
Maximum = 200" per minute

G = Good Quality Mults
P = Poor Quality Mults

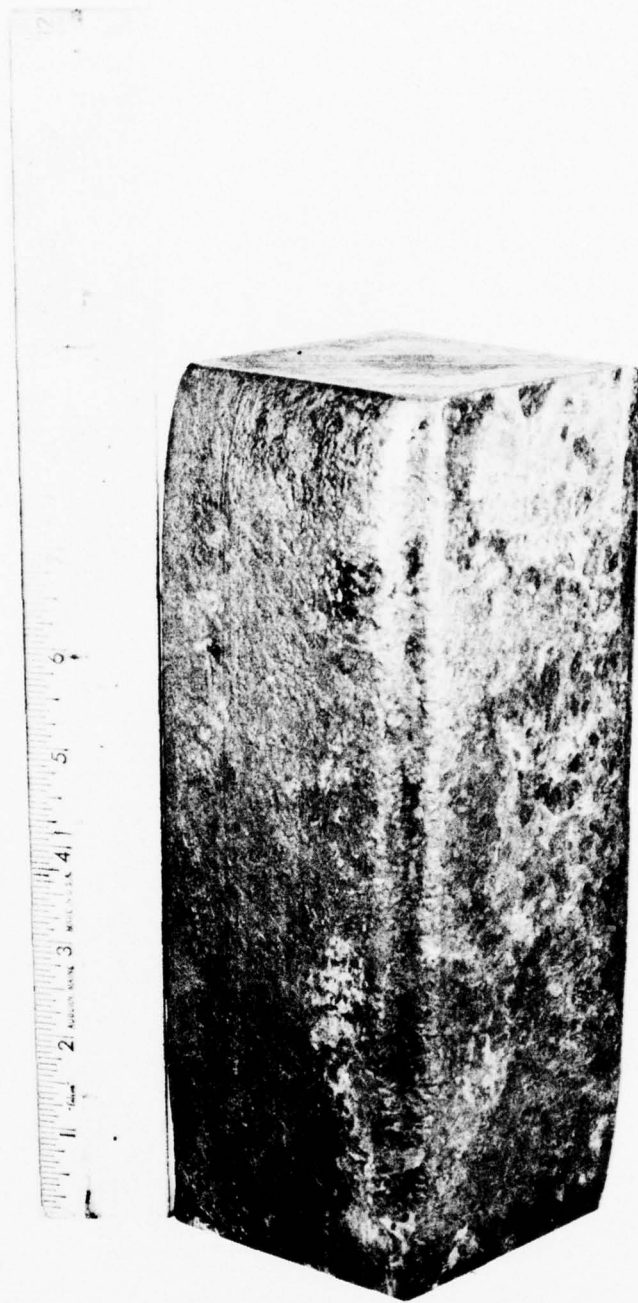


Figure 1. Side View of Hot Sheared Molt for
105 mm M1 Projectile.

Table 3. Chart Depicting Mult Quality for Various Process Parameters Investigated for 1046 and HF1 Steels.

Blade Clearance Steel Grade	Temperature (°F)															
	2250	2200	2175	2150	2100	2050	2000	1975	1950	1900	1850	1800	1750	1700	1650	1600
.015" 1046	G		G			G		G		G		G	G		G	G
.020" 1046	P	P	G	G	G	G	G			G	G	G		G	P	
.028" 1046	G			G	G				G		G		G		P	P
.020" HF1				P	P	P	G		G	G	G	G	P	P	P	P

Shear Blade Speed for all tests was 200" per minute

G = Good Quality Mults
P = Poor Quality Mults

C. Hot Shear Study on 155 mm M107 at Twin Cities AAP

While the hot shear press to be installed at National Presto was being built, Caterpillar Tractor Company in East Peoria, IL was building a new forge line for forging of track support rollers for Caterpillar tractors. This line incorporated hot shearing of mults from 6" round cornered square starting stock. The hot shear press used in this line was the same model as the one being procured for installation at National Presto.

Personnel from Caterpillar Tractor Company were contacted to determine if it would be possible for them to hot shear some mults in the 6" round cornered square size. Delays in placing the overseas contract for the government's hot shear press had put this program behind schedule so it was decided some early answers relative to hot shearing of mults for projectile forging could be obtained by having some work done at Caterpillar Tractor Company. Caterpillar personnel agreed to hot shear some material for the government provided this work could be done while they were in the debugging phase of setting up their forge line. They pointed out that once their equipment was placed in full production they would not be able to assist the government in this project.

A contract was placed with Donovan Construction Company, New Brighton, MN, the operating contractor of Twin Cities Army Ammunition Plant (TCAAP) to ship 100 tons of steel regularly used in production of the 155 mm M107 projectile at TCAAP to Caterpillar for hot shearing into mult lengths. These mults were then returned to TCAAP for processing into 155 mm M107 projectiles. As previously explained, hot shearing of this material was done while Caterpillar was debugging their induction furnace and some problems were encountered. Out of a total of 1705 mults processed, 561 projectiles had to be scrapped because of the possibility of overheating. Control problems were being experienced with the furnace at the time the 561 mults representing these projectiles were hot sheared so rather than take a chance on having overheated projectiles get into the field it was decided to scrap this material. Results of processing these mults into projectiles were not typical of results achieved when processing mults that had not been overheated; therefore, this data was disregarded in this study.

A total of 1144 mults, representing material that had not been overheated, were processed into 155 mm M107 projectiles at TCAAP. A breakdown of the various groupings of mults representing the total of 1144 is shown in Table 4.

TABLE 4. Group Identification of Hot Sheared Mults Processed at TCAAP

<u>Group I</u>	<u>Color Code</u>	<u>Condition</u>	<u>Weight</u>	<u>Press Line</u>	<u>No. Mults</u>
1	Red	Smooth Ends	120-122	Elms	470
2	Blue	Smooth Ends	122-125	Baldwin	436
3	White	Manipulator Marks on Ends	120-122	Elms	74
4	Yellow	Manipulator Marks on Ends	122-125	Baldwin	<u>164</u>
Total					1144

In Table 4, "Condition" refers to the condition of the ends of the hot sheared mults. In Caterpillar's normal operation, they use a manipulator device to grip the ends of the hot sheared mults to move them into their forging press. This device imparts a rather deep hemispherical impression into the ends of the mults. For Caterpillar's forging, these impressions do no harm; however, during initial shearing of the steel from TCAAP, government and Donovan personnel explained to Caterpillar personnel that for projectile forging applications, these impressions could cause problems. Caterpillar personnel designed a new holding device for their manipulator for processing of the steel from TCAAP. Apparently, at some later point in time, someone forgot to remove the regular manipulator and hot sheared mults with manipulator marks resulted. Groups 3 & 4 in Table 4 represent the mults with manipulator marks in hot sheared ends.

All hot sheared mults were weighed at TCAAP and grouped into two weight groups as shown in Table 4. Caterpillar had been requested by Donovan personnel to hot shear mults using three different mult lengths. The reason for using various mult lengths was to determine if the mult weight could be reduced by going to hot shearing. As explained previously the nick & break process is not a very exact method of billet

separation and mults typically must be broken over weight to compensate for the fact that an angular break could result in a mult too light to make an acceptable projectile. The weight of the mult aimed for in regular production using nicked & broken mults is 122-124 lbs.

As shown in Table 4 there were two press lines used at TCAAP during this study. The Elms line uses conventional forging press tooling with die pot fixed and press ram and punch moving down to make a pierced forging. This line has a cabbage and pierce forging sequence. In the Baldwin line, the mult for forging was placed on the rim of a ring, the die pot which was on top moved down over the mult; afterwhich, the piercing punch entered and pierced the forging. There was no cabbage operation on this line.

Of the total of 1144 hot sheared mults that were started through the forging shop, 1106 projectile forgings were made as indicated in Table 5.

TABLE 5. Pieces Lost During Forging Operation at TCAAP

<u>Forging Line</u>	<u>No. Lost</u>	<u>Reason for Loss</u>
Baldwin	22	15 mults would not sit upright on ring 7 mults too cold for forging (Withdrawn from furnace and brief press shutdown)
Elms	16	7 Due to breakdown of manipulator tongs 8 Too cold for forging 1 No Boss on forging

The 15 pieces that wouldn't sit upright in the forging press were the only rejects that can in any way be related to the fact that hot sheared mults were being run. The slight lip caused by pull down during hot shearing was blamed as the cause of these pieces not sitting properly on the ring. All fifteen of the mults where this problem occurred came off the Baldwin line which was the non-conventional line as described above. Since such an arrangement of forging tooling would never be considered in any modernized forge facility using the hot shear concept of billet separation, the problem has no significance. On the more conventional Elms line, there were no problems experienced that in any way could be related to the fact that hot sheared mults were being processed. Concentricity of forgings off both the Baldwin and Elms lines was reported as being good.

Of the 1106 forgings processed through rough turn, 44 pieces were rejected for various reasons as indicated in Table 6.

TABLE 6. Tabulation of Rejects During Rough Turn at TCAAP

<u>Group</u>	<u>No. Rejects</u>	<u>Reason for Rejection</u>
1	1	Deep Boss
	1	No Boss
2	0	
3	2	Center drill broke caused by manipulator mark
	4	Short Shell
	17	Base pits due to manipulator marks
4	1	Exterior pits (Not hot shear related)
	3	Center drill broke caused by manipulator mark
	10	Deep holes in boss due to manipulator marks (Shell not processed further)
	1	Short Shell
	4	Base pits due to manipulator marks

If one considers only the smooth end mults (Groups 1 & 2) there were only two rejects, neither of which can be related to hot sheared mults. The primary cause of rejects in Group 3 & 4 was the manipulator marks inadvertently put in the ends of the hot sheared mults at Caterpillar.

The cavities of all rough turned shell were visually inspected. Line inspectors stated the cavities of this special group of shells were better than regular production. This manifested itself in less grinding of projectile cavities to clean out defects.

A total of 1062 shell were processed through nosing. Of this quantity, 1033 shell were processed through the final inspection station prior to paint. Of this quantity, 260 projectiles were magnetic particle inspected and two projectiles were screened out for magnetic particle indications. One of these indications appeared to be a seam defect approximately 3/4" long near the rear bourrelet and the other projectile had cracks in the I.D. nose thread area. Both of these projectiles were returned to Frankford Arsenal for further metallurgical examination; however, neither defect was found to be related to the hot sheared starting mults. The projectile with nose cracks was detected visually prior to magnetic particle inspection. The remaining quantity of 27 projectiles making up the difference between 1062 and 1033 represented projectiles that were set aside for rework at various operations and, therefore, did not pass through the final inspection station with the other quantity of 1033 shells.

The 1033 projectiles finally processed through final inspection during this test were assigned a separate TCAAP lot number of 6-1. Ballistic samples were selected from this lot and tested in the normal manner. No problems were encountered in the ballistic test and the lot was accepted.

During final inspection line inspectors doing cavity inspection stated the cavities of this special group of shells were much better than regular production projectiles made using nicked & broken mults. Out of the total of 1033 shells which were inspected at this station, only three had to receive any cavity rework by grinding. The operator doing the grinding stated that in regular production a significantly higher percentage of shells require cavity repair by grinding. This became obvious when regular production shell were started through the line after processing of the special shells and the grinding rework area became filled with shells in a very short time.

A photograph showing the hot sheared end surface of one of the hot sheared mults processed at TCAAP is shown in Figure 2. This photograph shows that the end surface quality of mults hot sheared at Caterpillar was quite good. All billets sheared during this study were sheared on the diagonal; therefore, lines running from the lower right hand corner of the mult surface are striations caused by the shear blade. Since the end deformation on mults used at Caterpillar is not as critical for their forging application as it is for projectile forging, no significant effort had been made at Caterpillar to achieve minimum deformation. By optimizing blade clearance and design, it should be possible to minimize end deformation below that experienced at Caterpillar. Maximum corner pull down on mults hot sheared at Caterpillar was approximately 0.6". On the opposite corner a shear lip of 1/8" maximum was observed. It was this shear lip which prevented some hot sheared mults from sitting upright in the ring stand of the Baldwin press as previously discussed.

D. Summary of Hot Shear Study Results

A summary of the hot shear study parameters and test results is presented in Table 7. In addition to obtaining some early answers relative to whether hot shearing could be used for projectile manufacture, there were other advantages of conducting hot shear studies at both National Presto and TCAAP. These advantages were:

1. Hot shearing of two different sizes and grades of steel could be evaluated. National Presto uses 3 1/2" RCS 1018 grade steel for manufacture of the 105 mm M1 projectile and TCAAP uses 6" round cornered square (RCS) 1050 grade steel for manufacture of the 155 mm M107 projectile.

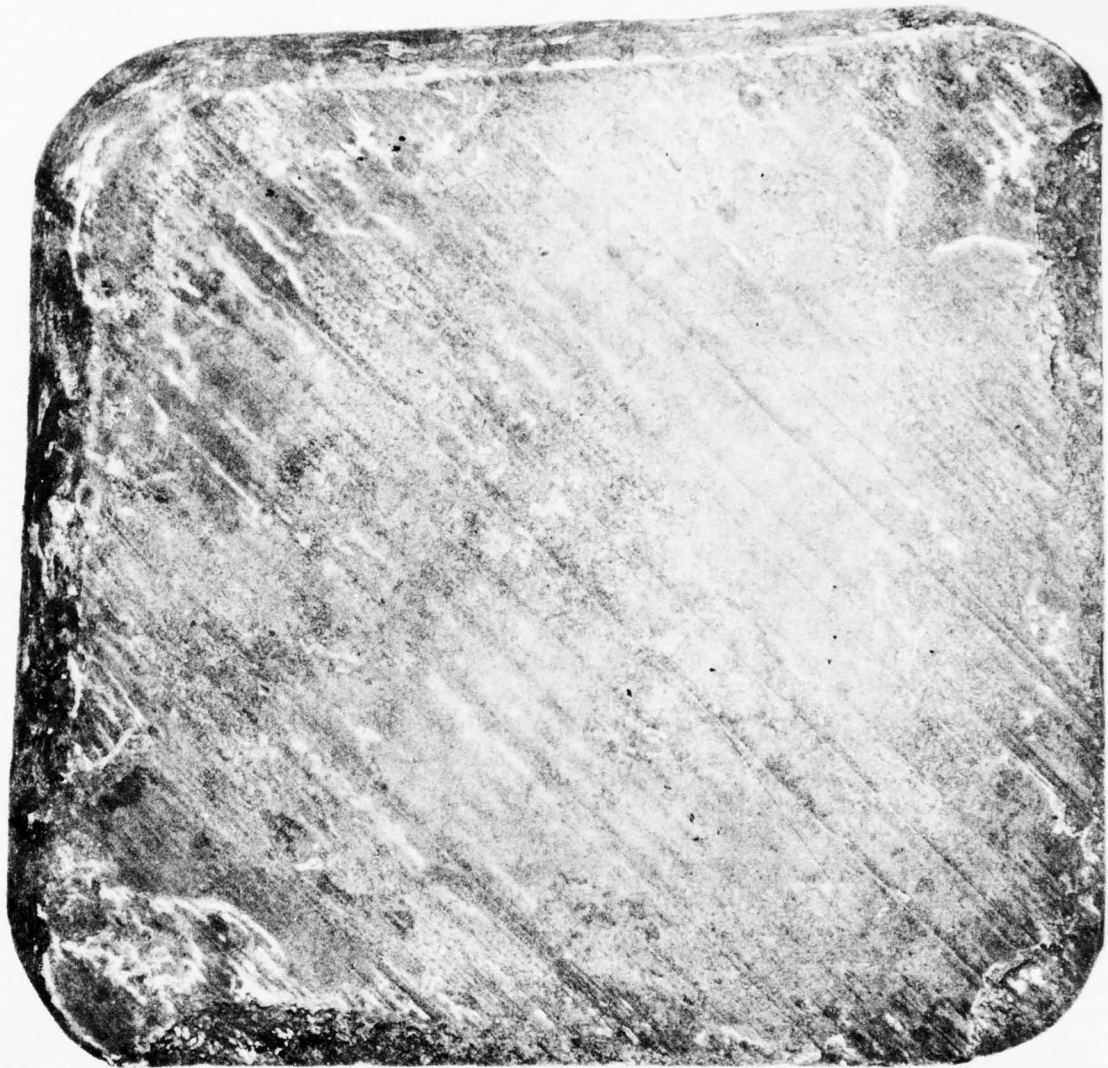


Figure 2. End View of Hot Sheared Mult for 155 mm
M107 Projectile.

TABLE 7. Hot Shear Study Parameters and Test Results

<u>Projectile</u>	<u>Contractor</u>	<u>Current Process</u>	<u>Tests Results</u>
105 mm M1	National Presto Eau Claire, WI	1018 Grade Steel 3½" Billet Stock Saw Mults Hot Cup - Cold Draw	No problems in processing hot sheared mults. $\pm .11$ lbs. Weight tolerance - $\pm .2$ lbs. for sawing. Length tolerance - $\pm .011$ " versus .020" for sawing. Face Angle - 10 versus 1.50 for sawing. Surface Quality - Equal or better than sawn mults.
155 mm M107	Donovan Construction Co., Twin Cities AAP New Brighton, MN	1050 Grade Steel 6" Billet Stock Nick & Break Mults Hot Forge	No problems in processing hot sheared mults. Surface Quality - Much better than Nick & Break. Significant Improvement in Projec- tile Cavities.

2. Hot sheared mults would be evaluated using both the hot forge and hot cup-cold draw methods of projectile manufacture. National Presto uses the hot cup-cold draw process and TCAAP uses the hot forge process.

3. Hot sheared mults could be compared with both the sawing and nick & break methods of billet separation. National Presto saws their mults and TCAAP uses the nick & break process of billet separation.

The basic conclusion of the work done at National Presto was that 105 mm M1 projectiles can be successfully made from hot sheared mults using the hot cup-cold draw method of manufacture. One of the significant findings of this study was that in terms of tolerance on length, weight control, perpendicularity and overall quality of parted surface, hot sheared mults equaled or exceeded the results currently achieved at National Presto using the band saw method of separation. Sawing up to this time had been considered to be the most exact method of separation. Another important aspect of the work at National Presto was that hot sheared mults were successfully processed into projectiles using the hot cup-cold draw process. The hot cup-cold draw process is recognized as requiring a higher quality starting mult than the hot forge process of manufacture. Absolutely no problems were encountered in using hot sheared mults at National Presto.

Results of the study at TCAAP showed that hot sheared mults can be successfully processed into 155 mm M107 projectiles by the hot forge process of manufacture. One of the important findings of this study was the significant improvement in the quality of forged projectile cavities processed from hot sheared mults as compared to nicked and broken mults.

E. Hot Flame Cutting Study

Early in this study there was some concern about how to part the last mult from the discard when using the hot shear concept. The reason for this problem was that a minimum hold down length equal to the size of stock being sheared is required to obtain a satisfactory hot sheared mult. This means for example that when hot shearing 3 1/2" RCS stock, a minimum of 3 1/2" must be in the inboard hold down device. This minimum hold down length is required to prevent pulling or dragging of metal out from the hold down during the shearing stroke. The concern was that a minimum of 3 1/2" of stock would have to be discarded from each billet length when using the shear system.

The approach taken by Caterpillar in their production line relative to this problem was to kick out the last mult plus discard in each billet length, cool this piece to room temperature and then saw to mult length.

Caterpillar's induction heaters have been specially designed such that they can place up to two mult lengths between billet lengths within the induction furnace. The excessive amount of handling and the complications of induction furnace design created when it is necessary to handle both mults and billet lengths made this option undesirable for high volume projectile manufacture.

Another suggested solution to this problem was to kick out the last mult plus discard, hot flame cut to mult length and then immediately reintroduce the flame cut mult into the forge line. It was theorized it would be possible to hot flame cut the mult fast enough that minimum heat would be lost and it would be possible to reintroduce the mult to the forge line without application of any additional heat.

The problem was that no information was available relative to hot flame cutting of steel for subsequent forging application and very little information was available about the quality that could be expected from a hot flame cutting operation. To obtain answers to these questions, National Presto Industries, Inc., conducted a hot flame cutting study. Their report relative to this study is contained in Volume 3.

The basic findings of this report were that the quality of flame cut mults was adequate for production of the 105 mm M1 forging with one exception. That exception was slag which clung to the bottom edge of the mult. The slag produced by the cutting process clings tenaciously to the heated steel at the kerf edge and precludes production of acceptable forgings on a reliable production basis unless the slag was mechanically removed prior to the forging operation. Based on this it was concluded that hot flame cutting would not be an acceptable auxilliary parting method for use with the hot shear system. For complete details of the hot flame cut study see Volume 3.

VIII. DESIGN CONSIDERATIONS FOR IMPLEMENTING HOT SHEARING INTO A PROJECTILE FORGING LINE

A. Furnace Considerations

When considering hot shearing for implementation into a forge facility one of the first considerations must be heating equipment for forging. To use the hot shear concept of billet separation, furnace equipment capable of heating billet lengths of steel (20-24 foot length) to forging temperature is required. All existing forge furnace equipment in projectile manufacturing facilities is designed to heat mult lengths of steel. Herein lies the first criteria

for implementation of hot shearing; that is economic justification must be established for replacement of existing furnace equipment with equipment capable of heating billet lengths of steel to forging temperature. Of course, in the case of a new facility where new equipment is required this criteria does not apply.

Two possible furnace designs have been considered for incorporation into a hot shear system. One design is based on a walking beam type, oil or gas fired furnace, and the other design is based on either an induction furnace or barrel type, oil or gas fired furnace.

The schematic representation shown in Figure 3 depicts the arrangement of equipment when using an induction furnace or a barrel type gas or oil fired furnace. The unscrambling table would be supplied with billets from the storage area by overhead crane. The unscrambling table would unscramble the billets for orderly movement onto a transfer conveyor for charging into the entrance end of the furnace. The transfer conveyor would be designed so that on demand, a billet would be automatically moved into the furnace such that one billet would follow the other through the furnace in a continuous manner. The billet lengths would be moved through the furnace by powered rollers between each individual furnace unit as shown in Figure 3. These rollers would drive the billets through the furnace as well as support the billets within the furnace. As the billet exits from the furnace it would be at forging temperature and move directly into a hot shear press. The billet would pass through the shear press and move up against a stop pre-set at the desired mult length. The billet coming to rest against this stop would signal the hot shear press to cycle and a mult of desired length would be hot sheared. This cycle would be continued automatically at the demand of the forging press. After hot shearing the mult would move by conveyor through a water descale operation and then immediately to the forging press for forging into a projectile body.

Operation of the walking beam billet heating furnace - hot shear system depicted in Figure 4 would be similar to the system described above except the method of billet transfer through the furnace and the furnace design would be different. In this system, cold billets would be moved by the transfer conveyor through a small door in the side of the walking beam furnace. Once the entire billet was in the furnace it would be picked up and walked progressively through the furnace on a walking beam mechanism. After the billet moved through the furnace and was heated to forging temperature it would be transferred from the walking beam to a powered roller conveyor which would carry the billet out of the furnace through a small door in the side of the furnace as depicted in Figure 4. A hot shear press would be located adjacent to the furnace and would operate in the same manner as previously described for the furnace system depicted in Figure 3.

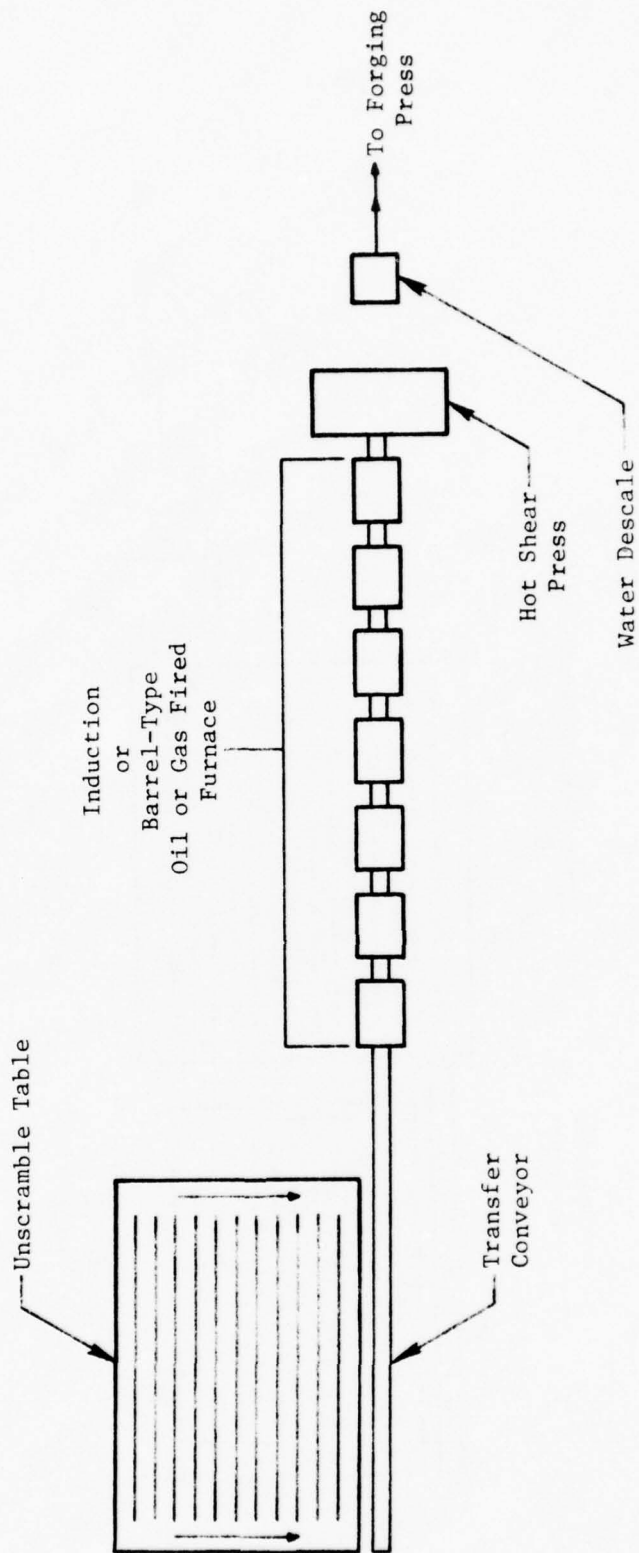


Figure 3. Furnace - Hot Shear Press System Using Induction or Barrel-Type Oil or Gas Fired Furnace.

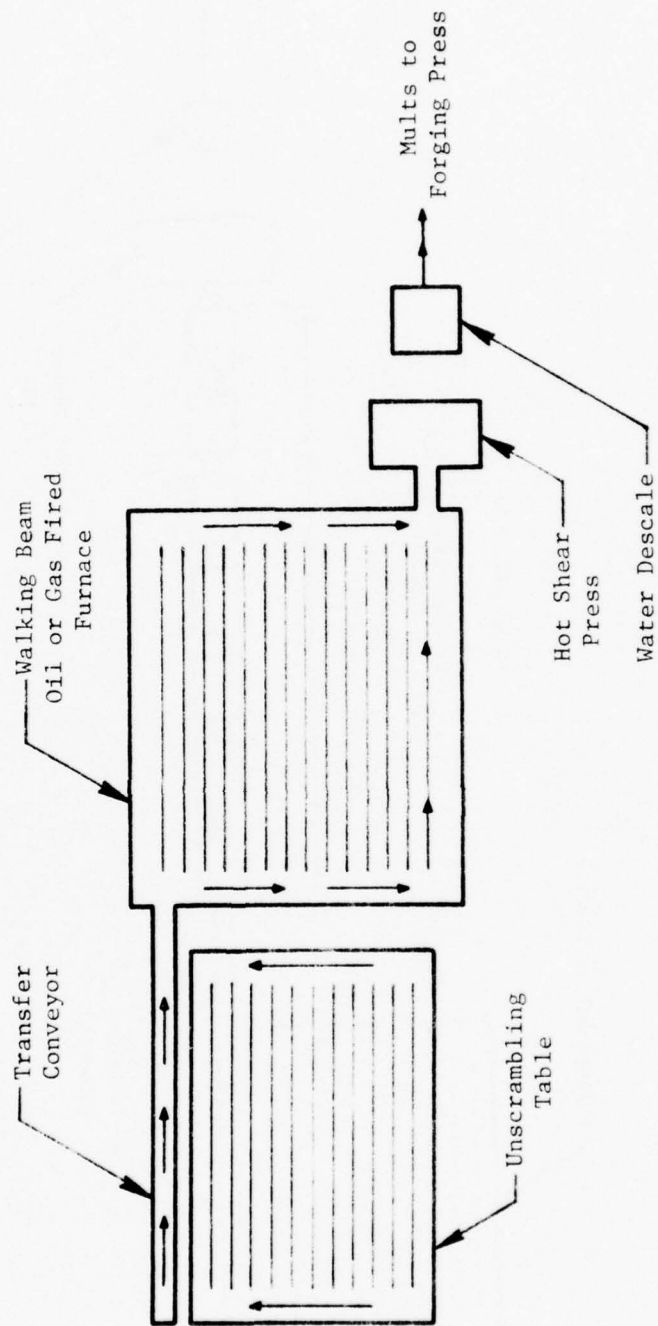


Figure 4. Furnace - Hot Shear Press System Using Walking Beam Oil or Gas Fired Furnace.

B. Methods of Handling Last Mult Plus Discard in Each Billet Length

As discussed previously under the hot flame cutting study, one question that had to be answered with respect to the hot shear system was how to separate the discard from the last mult in each billet. The reason for this problem is that a minimum hold down length equal to the size of stock being sheared is required to obtain a satisfactory hot sheared mult. Without this minimum hold down length of steel, there is a tendency for the steel in the hold down to be pulled or dragged out of the hold down during the shearing stroke. The concern was that a minimum discard from each billet equal in length to the size of stock being sheared would be wasteful of material and result in an additional cost which should be avoided if at all possible.

Various techniques were considered to minimize the discard from each billet length. Since steel billet stock can be purchased to a specified length with a +2" tolerance on length, the best situation would be one where the only discard would be the stock representing the tolerance length (from 0 to 2 inches) on each billet length. Of course, the truly ideal situation would be if billet stock could be purchased by weight instead of by length. Then the billet weight could be ordered to some multiple of the desired mult weight and the billet could be hot sheared into some exact number of mults with no discard. Since steel companies do not sell steel billets by weight at this time, this approach could not be considered.

The various techniques considered to minimize discard in each billet length were as follows:

1. Remove last mult plus discard from hot shear press, cool to room temperature and then part discard from mult length by some conventional means such as sawing or flame cutting. The extra material handling plus the need to reheat the mults parted in this manner in some auxilliary furnace does not make this an attractive approach.

2. Remove last mult plus discard from hot shear press, hot flame cut mult length and then immediately reintroduce mult to forging line without applying any additional heat. As discussed under the hot flame cutting study this is not an acceptable technique because of the slag which clings to the bottom edge of the hot flame cut mult.

3. Use of a back gauge was considered. Using this concept a detector would be mounted at the entrance side of the hot shear press to detect when the last mult plus discard was entering the hot shear press. When this last piece was detected a back gauge would come up behind the piece and locate at a distance of one mult length from the ingoing side

of the shear. At this point the discard would be sheared from the mult, leaving the mult lying in the shear hold down ready to be pushed through the shear and into the transfer conveyor by the next oncoming billet. This technique was discarded since it would cause too much interruption to the desired continuous flow of material under high volume production conditions. When working at production rates of 720 hot sheared mults per hour per forge line, the time lost by withdrawing the billet, inserting the back gauge, shearing, withdrawing the back gauge and re-advancing the billet would be too time consuming. In addition, the extra space required between the furnace and the shear to fit the back gauge mechanism would result in additional loss of temperature before shearing took place which would prejudice normal running of the equipment.

4. Measure length of each billet prior to entering furnace and set measuring stop on hot shear press such that billet was divided up into a specific number of equal length mults with no discard. This technique would require use of a mini-computer to store information on each billet length and to automatically set the measuring stop on the hot shear press. It is believed this technique would work with one possible exception. If a billet came in at minimum length (specified length with zero minimum additional length for tolerance) and if the hot sheared mults in that billet were all cut to maximum length within the accuracy of the hot shear press, the last mult could be underweight and have to be scrapped. Production history on this technique would be required before the feasibility could be definitely established.

5. Use hold down mechanism on both the inboard and outboard side of the hot shear press. This technique is very simple and is one which will permit separation of short discard lengths from the last mult. By using a hold down on the outboard side of the hot shear press, the problem of dragging or pulling material from the inboard hold down when short lengths are in this hold down is eliminated. Shear press manufacturers have stated there would be no problem to furnish a hot shear press with hold downs on both the inboard and outboard side of the press. In fact, many cold shear presses are now being designed this way to minimize bending moments during cold shearing which can cause shear cracking.

C. Use of Cut-To-Weight System in Conjunction with Hot Shearing

One of the problems associated with the use of semi-finished forging quality billet stock is that this material is supplied with a $\pm 2\frac{1}{2}$ percent tolerance on weight. Billet stock is purchased to some specified nominal cross sectional dimension with a corresponding nominal weight per unit length; however, the tolerance on weight is $\pm 2\frac{1}{2}$ percent of the

nominal weight. This means, for example, that if an 80 lb. mult is required to make a projectile, up to 4 lbs. extra steel could be in the mult that is cut to the length required to always assure getting a minimum mult weight of 80 lbs.

Current practice in projectile manufacture when ordering steel billets is to specify the billet length to some multiple of the minimum mult length required to make a specific projectile. The following example will show how it is possible to obtain an extra mult from a billet length due to the tolerance on weight per unit length of billet stock.

Material - $5\frac{1}{4}$ RCS Billet Stock (Nominal wt. per ft. = 93 lbs.)

Minimum Mult Wt. - 80 lbs.

Minimum Mult Length - 10.6"

Specified Billet Length - 23.85 ft. *

Number Mults per Billet - 27 *

* Assume manufacturer wants to use approximately 24' length billet stock. When specifying billet length, the order would request steel in multiples of 10.6" (the minimum mult length). $27 \text{ Mults} \times 10.6" = 23.85 \text{ ft.}$

As pointed out above, up to 4 lbs. extra steel could be in each mult or 108 lbs. over the entire billet length which is enough to obtain an extra mult. It is immediately obvious that significant material savings could be achieved if a method of cutting mults to weight instead of to length could be found.

Technical information on a cut-to-weight system was obtained during this project from Lamberton & Company, LTD, Coatbridge, Scotland. Lamberton has designed, built and sold several cut-to-weight billet parting systems which are currently in operation in Europe. A schematic diagram showing the various operating elements of a Lamberton cut-to-weight system are shown in Figure 5. The basic operation of this system is as follows:

1. Billets are transferred from unscrambling table onto feed conveyor which moves the billet forward until it comes to rest against a disappearing datum stop.
2. Feed conveyor is lowered, placing billet down onto two load cells.

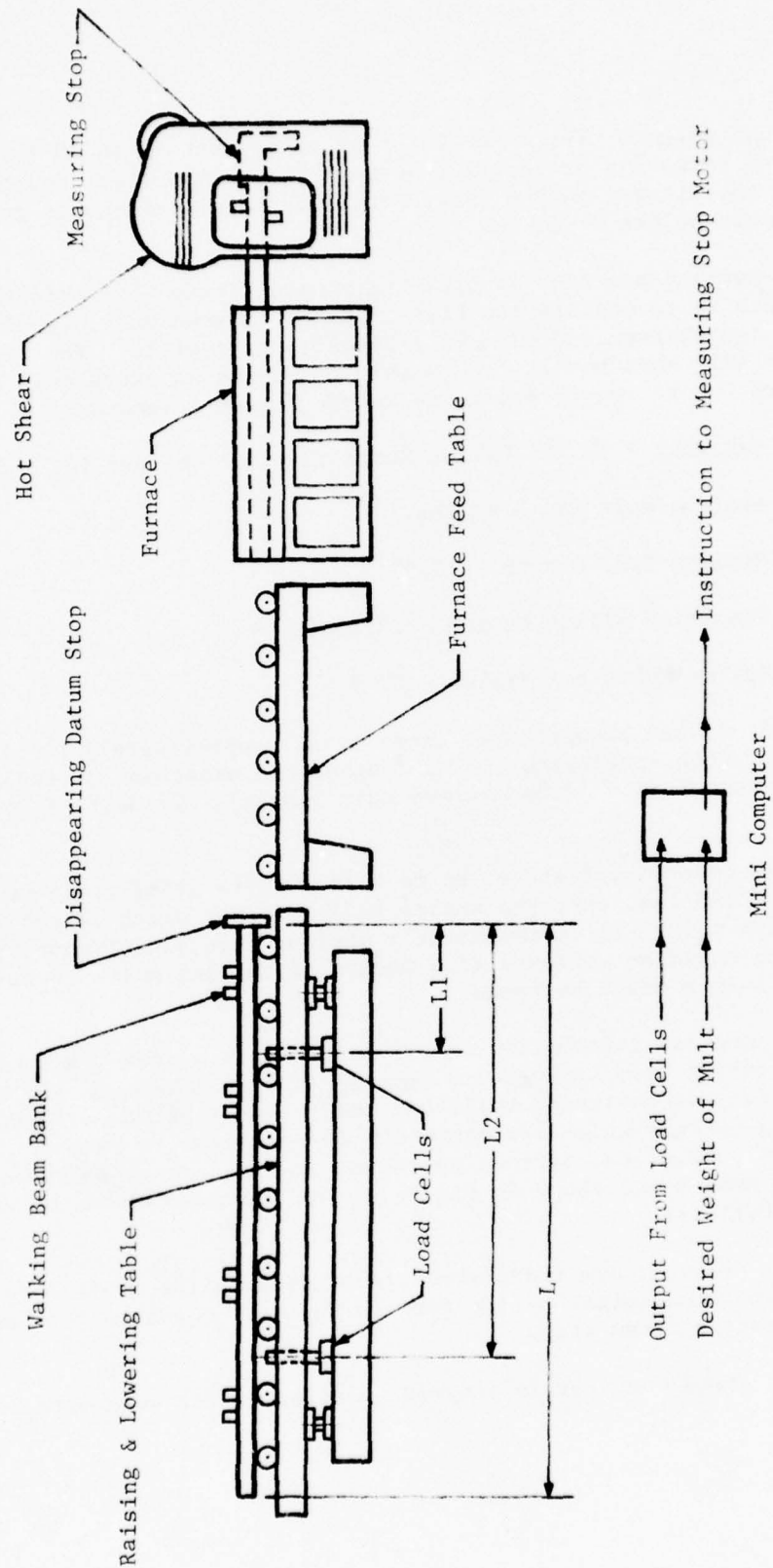


Figure 5. Cut-To-Weight Billet Parting System.

3. Weight recorded on each load cell is fed to mini-computer. Since distances from datum stop to load cells (L_1 & L_2) are fixed, the computer is able to determine length of billet by taking moments from the two load cell locations. The total weight of the billet is computed by adding weight from each load cell. With this information the computer can now calculate weight per unit length of billet. The weight per unit length of each billet is stored in the computer until the billet is ready for hot shearing into mult lengths.

4. Desired mult weight selection is made at computer console. With the information now available, the computer can provide an instruction to the hot shear measuring stop for automatic adjustment to achieve desired mult weight.

Lamberton will guarantee a $\pm 3/4$ percent weight tolerance on hot sheared mults using their cut-to-weight system. Based on this weight tolerance, significant material savings are possible over cut-to-length methods depending on certain other variables. The material savings which can be achieved by the cut-to-weight systems is sensitive to two variables which are (1) length of mult being cut and (2) length of starting billet length. The sensitivity to mult length results from the fact that material savings are achieved by being able to obtain an extra mult from a billet length a certain percentage of the time. As the mult length increases, the probability of being able to obtain an extra mult decreases. The sensitivity to starting billet length results from the fact that as the billet length increases the probability of obtaining an extra mult increases. With increased billet length, the number of mults per billet will increase resulting in a greater overall accumulation of potential excess material which increases the probability of obtaining an extra mult length from the billet.

Calculations have been made to estimate the material savings which could be achieved in manufacture of the 105 mm M1 and 155 mm M483 projectile bodies using the cut-to-weight system. These calculations are based on monthly production of one million 105 mm M1's and 120,000 155 mm M483's. The actual calculations showing the material savings are included in the Appendix. To show the sensitivity to variation in mult length, calculations were made for nominal billet lengths of 20 and 24 feet for the 105 mm M1. The material savings for these two items and nominal billet lengths of 20 and 24 feet are shown in Table 8. The sensitivity to variation in mult length is observed when comparing savings for the 105 mm M1 against the 155 mm M483. For the 155 mm M483 when a nominal 20 foot billet length is used no savings are realized compared to a savings of .56 lbs./shell when using a nominal 20 foot billet length for the 105 mm M1. Increasing the nominal billet length

from 20 to 24 feet for both the 105 mm M1 and 155 mm M483 results in significantly increased material savings.

TABLE 8. Material Savings for Manufacture of 105 mm M1 and 155 mm M483 When Using the Cut-To-Weight System

<u>105 mm M1</u>	<u>Material Savings lbs./shell</u>	<u>Material Savings* per month</u>
Nominal 20 foot length billet	.56	\$ 70,000
Nominal 24 foot length billet	.85	\$106,500
<u>155 mm M483</u>		
Nominal 20 foot length billet	None	None
Nominal 24 foot length billet	1.03	\$ 21,700

* Based on monthly production of 1,000,000 105 mm M1's and 120,000 155 mm M483's.

The cut-to-weight system of billet separation is considered to be a state-of-the-art technique currently being used successfully by forge shops in Europe. Potential suppliers of billet heater-hot shear press systems in this country state that they do not see any problems in incorporating the cut-to-weight technique into this system provided furnaces of the in-line type shown in Figure 3 are used. With walking beam furnaces of the type shown in Figure 4, weight per unit length information would have to be stored on all billets in the furnace. This could create a problem. Also the walking beam type furnace would cause more scale loss to the billets because of greater exposure time in the furnace which could compound the problem of trying to cut-to-weight. The specific problem would be variation in scale loss when billets are in the furnace for longer than the normal cycle due to down-time at the forging press.

Due to the sensitivity of material savings to mult length and starting billet length, each application must be carefully evaluated prior to incorporation of the cut-to-weight technique into a forge line. Based on the calculation made during this study, the cut-to-weight technique is recommended for both the 105 mm M1 and the 155 mm M483 provided nominal 24' length billets are used. For the 105 mm M1, cost savings can be achieved using a nominal 20 foot length billet; however, the 51 percent increase in material savings achieved by going to a nominal 24 foot billet makes the use of the longer length billet an important consideration for this shell also.

D. Miscellaneous Design Considerations

1. Hot Shear Down, Whole Line Down - One of the disadvantages of the hot shear system that has been put forth is that if for some reason the hot shear is not operating the whole forge line will be shut down. Since the hot shear is an integral part of the forge line, it is a fact that production of the forge press is directly dependent on operation of the hot shear press. This potential disadvantage of the hot shear system has been discussed with personnel from three current users of integrated forge lines using hot shearing. These personnel have stated that the hot shear equipment has been found to be very reliable and they have not experienced any significant forge line down time directly related to down time on the hot shears. In fact personnel from one company stated that during the first year of operation of their new forge line, they could not remember one time when the forge line was down due to a maintenance problem on the hot shear press. They were quick to point out that they had experienced many problems when the forge line was first put into service but none were incurred on the hot shear press that caused the forge line to be shut down. Regularly scheduled maintenance has been established at each of the manufacturer's plants for such things as changing shear blade tooling. By closely adhering to a scheduled maintenance program, unscheduled down time on the forge line caused by the hot shear press has been minimized to the extent that forge line shut downs caused by down time of the hot shear press have not been found to be a problem.

2. Purchase Hot Shear as Part of System - When using the hot shear concept of billet separation, the entire line from unscrambling table up to delivery of hot sheared and descaled mulds to the forging press must operate as a fully integrated system with all units synchronized with each other for automatic operation. Therefore, it is considered imperative that the hot shear press be purchased as part of a complete furnace - hot shear press system with one contractor responsible for the entire system. Purchase of individual units of the system from various contractors could mean failure of the units to operate in a synchronous and automatic mode once the units were linked together. It is understood that there will most likely not be one equipment builder capable of furnishing all the equipment required for a complete furnace - hot shear system; however, a prime contractor representing either a furnace or hot shear press builder could be selected who would in turn sub-contract for any equipment which the prime could not build himself. With regard to the hot shear press, numerous U.S. manufacturers of press equipment have now expressed interest in supplying hot shear press equipment. This response is quite different from the situation that existed when this project was first initiated and no U.S. companies were interested in furnishing such equipment.

3. Auxiliary Mult Heater - An auxiliary furnace should be provided as part of any forge facility set up to use the hot shear concept of billet separation. This auxiliary furnace would be used on an intermittent basis as required to heat mult lengths that become sheared to length but because of forging press shutdown do not become forged. This auxiliary furnace is required since the basic furnace being used will be designed to heat billet lengths and therefore its material handling system will not be capable of heating mult lengths. One induction heating furnace now in operation in a hot shear system has been designed to heat both billet lengths and mult lengths on a limited basis. However, this dual heating capability complicates the design of the furnace to such an extent that this approach is not considered desirable for high volume projectile forging applications. Use of an auxiliary furnace is considered to be a more reliable and less costly approach.

4. Detection System for Unstraight Billets - When an induction furnace is used, billets would be purchased to commercial bar straightness requirements of $\frac{1}{4}$ inch per 5 inches of billet length and the furnace would be built to handle billets at twice this tolerance. However, to preclude the possibility of an unstraight billet getting into the induction furnace and damaging the induction coils, a detection system should be incorporated into the infeed conveyor that would automatically reject billets falling outside the specified straightness tolerance.

IX. BENEFITS ASSOCIATED WITH HOT SHEARING

The qualitative benefits associated with hot shearing were discussed earlier in this report. In order to quantify these benefits, cost savings which can be achieved by hot shearing versus the nick and break method of billet separation have been determined. The nick and break process was chosen for this comparison because it is used most prevalently in projectile manufacture and is one of the least costly of the currently used billet separation techniques in terms of operating costs.

Benefits derived from hot shearing versus the nick and break method of billet separation are related to reduced material handling costs, material savings, through use of lighter and more uniform weight multis, reduced scrap losses at both the billet parting and forging operation and the greater efficiency which would result from an integrated heating, billet separating concept.

A. Reduced Material Handling

In the hot shear concept of billet separation, billet stock is heated to forging temperature, parted while hot to the appropriate mult size and then immediately forged. It is readily apparent that integration of the hot parting operation into the forging operation will reduce labor costs and material handling equipment since billet lengths will be loaded automatically into the furnace as opposed to nicking and breaking individual mults which then would have to be individually loaded and unloaded from the furnace. In the hot shear concept, after parting of heated billets into mults, the mults would move directly to the forging press with no intermediate handling.

B. Reduced Mult Weight

The nick and break method of billet separation is very inaccurate in terms of being able to part a given weight mult. The breaks are often irregular and/or occur at an angle. To compensate for this, the mult must be parted overweight to assure always having enough weight in the mult to make an acceptable shell. Conversely, the hot shear method of billet separation has been found to be very accurate in terms of weight control. Weight variation of $\pm .11$ lbs. was achieved on 105 mm M1 mults during the study conducted at National Presto. This equals or exceeds the results normally associated with sawing of mults, which up to this time had been considered to be the most accurate method of billet separation.

C. Improved Cavity Surface

For projectiles which are machined on the interior surface such as 155 mm M483 and 8" M509 projectiles, this benefit will not apply; however, for the vast majority of projectiles produced with as forged cavities, the benefits of hot shearing would be significant. The nick and break process often results in an irregularly parted surface with loose, partially severed metal on the end of the mult which in subsequent forging operations causes critical defects in the projectile cavity. In most instances these defects can be removed by grinding to make an acceptable projectile; however, a certain percentage of these defects are so deep that the projectile must be rejected. Scaling of the parted surface during heating for forging is another cause of cavity defects. The hot shearing technique results in a cleanly parted surface and since the parting is performed after heating, the scaling problem is minimized. Use of the hot shear technique would result in a significant reduction in cavity defects thereby reducing repair costs and scrap rate with an overall improvement in quality of projectile cavities.

D. Cut-To-Weight Benefits

Integration of heating and hot shearing into a synchronized process permits the incorporation and use of a cut-to-weight system. This system weighs and measures the length of each incoming billet so that a weight per length can be established. Using this information, the stop on the hot shear can be automatically set to cut to a given weight. The economic benefits of this system have been discussed previously in this report.

E. Monetary Savings

A summary of the cost savings per projectile associated with the use of the hot shear concept of billet separation for the 105 mm M1 and 155 mm M483 projectile are presented in Table 9. These two projectiles have been selected for this analysis since new manufacturing facilities are planned for these two items and hot shearing is being recommended for implementation at these new facilities. An explanation of how these figures were established follows the summary.

TABLE 9. Summary of Cost Savings Per Projectile
For Hot Shearing Compared to Nick and Break

	<u>105 mm M1</u>	<u>155 mm M483</u>
Raw Material	\$0.23	\$0.53
Labor	.17	.37
Reduced Scrap	.05	.07
TOTAL	\$0.45	\$0.97

(1) Raw Material Savings

Mult weight can be reduced a minimum of 1 and 2 lbs. per mult for the 105 mm M1 and 155 mm M483 projectiles respectively through elimination of irregular breaks experienced in the nick and break operation. The hot shear concept would provide mult length accuracy to achieve this savings, therefore:

$$(105 \text{ mm M1}) \quad 1 \text{ lb.} \times \$0.12/\text{lb.} = \$0.12/\text{shell}$$

$$(155 \text{ mm M483}) \quad 2 \text{ lbs.} \times \$0.175/\text{lb.} = \$0.35/\text{shell}$$

Material savings associated with cut-to-weight system (see page 34)

$$(105 \text{ mm M1}) \quad .85 \text{ lbs./shell} \times \$0.12/\text{lb.} = \$0.11$$

$$(155 \text{ mm M483}) \quad 1.03 \text{ lbs./shell} \times \$0.175/\text{lb.} = \$0.35$$

Total Material Savings

$$(105 \text{ mm M1}) \quad \$0.12 + \$0.11 = \$0.23$$

$$(155 \text{ mm M483}) \quad \$0.35 + \$0.18 = \$0.53$$

(2) Labor Savings

A comparison of labor required for the two methods of billet separation is presented below. The figures given represent men required per forge line. Fractional figures means one man would perform on two or more forge lines; i.e., $\frac{1}{2}$ man means a man would be used $\frac{1}{2}$ time on each of two forge lines.

Comparison of Men Required Per Forge Line

	Nick & Break		Hot Shear	
	105 mm	155 mm	105 mm	155 mm
Crane Operator	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Nicking Operator	1	1	0	0
Breaking Press Operator	1	1	0	0
Weighing & Inspecting of Mults, Chipping off Loose Metal and Handling of Mults	4	2	0	0
Operator of Surface Grinder to repair Cavity Defects	2	0	$\frac{1}{2}$	0
TOTAL	$8\frac{1}{2}$	$4\frac{1}{2}$	1	$\frac{1}{2}$

Manpower reduction per forge line

$$(105 \text{ mm}) \quad 8\frac{1}{2} - 1 = 7\frac{1}{2} \text{ men per line}$$

$$(155 \text{ mm}) \quad 4\frac{1}{2} - \frac{1}{2} = 4 \text{ men per line}$$

Cost Saving per Projectile

$$(105 \text{ mm}) \quad 7\frac{1}{2} \times \$11/\text{hr. (labor + overhead)} = \$82.50/\text{hr. savings}$$

$$\frac{\$82.50/\text{hr.}}{468 \text{ shell/hr./forge line}} = \$0.17/\text{shell saving}$$

$$(155 \text{ mm}) \quad 4 \times \$11/\text{hr.} = \$44/\text{hr. savings}$$

$$\frac{\$44/\text{hr.}}{117 \text{ shell/hr./forge line}} = \$0.37/\text{shell savings}$$

(3) Reduced Scrap

a. Scrap due to broken mults which are not usable due to irregular ends or weight out of tolerance is estimated at 0.5%.

$$(105 \text{ mm}) \quad \frac{.5\% \times 39 \text{ lbs.}}{\text{mult}} \times \frac{\$0.12}{\text{lb.}} = \$0.02/\text{shell savings}$$

$$(155 \text{ mm M483}) \quad \frac{.5\% \times 80 \text{ lbs.}}{\text{mult}} \times \frac{\$.175}{\text{lb.}} = \$0.07/\text{shell savings}$$

b. Scrap caused by forged projectiles with unrepairable cavity defects due to poor surface of nicked & broken mults is estimated at .5%.

Note: This scrap loss is applicable only to 105 mm M1 since 155 mm M483 has machined cavity.

Forging value estimated at \$5.50.

$$.5\% \times \frac{\$5.50}{\text{shell}} = \$0.03/\text{shell saving}$$

Total Scrap Saving

$$(105 \text{ mm}) \quad \$0.02 + \$0.03 = \$0.05$$

$$(155 \text{ mm}) \quad = \$0.07$$

APPENDIX A

CHARACTERISTICS OF HOT SHEAR PRESS PURCHASED
FROM RHEINSTAHL WAGNER

Effective shearing force, max.	225 metric tons
Hold down force, max.	25 metric tons
Operating pressure, max.	3,550 psi
Shear stroke, max.	14.4"
Maximum size square billet	7"
stock which can be sheared	
based on hot tensile strength	
of 10,000 psi	
Range of mult lengths which can	9-24"
be sheared	
Total drive power	140 HP
Calculated ram speeds	
Maximum advance	480 ipm
Shearing at 1,400 psi	210 ipm
Shearing at 3,550 psi	83 ipm

APPENDIX B

MATERIAL SAVINGS ASSOCIATED WITH CUT-TO-WEIGHT METHOD OF BILLET SEPARATION FOR 105 MM M1 FORGING (MINIMUM OF 28 MULTS PER BILLET, NOMINAL 20 FT. LENGTH BILLET)

GIVEN:	(A) Nominal weight of 4 X 4 RCS billet stock	= 54 lbs./ft
	(B) Weight variation due to varying cross sectional dimensions of billet stock	= $\pm 2.5\%$
	(C) Minimum mult weight required	= 38 lbs.
	(D) Mults per billet (minimum)	= 28
	(E) Tolerance on billet length	= + 2"
	(F) Tolerance on mult length	= $\pm .025"$
	(G) Weight variation in mults cut by weight	= $\pm .75\%$
	(H) Monthly production for LSAAP	= 1,000,000 projectiles
	(I) Steel Cost	= \$0.125/lb.

- ASSUMPTIONS:
- (A) Normal distribution in weight variation of billet stock.
 - (B) Normal distribution of + 2" tolerance on length of billet stock.

CALCULATIONS

1. Determine length of billet stock to be ordered when cutting to length (current practice) such that 28 mults are always obtained.

When cutting to length two variables must be considered to always assure getting 38 lb. mult as follows:

a. Variation in mult weight due to variation in billet weight per unit length (2.5%) - $.025 \times 38 \text{ lbs.} = .95 \text{ lbs.}$

b. Variation in mult length ($\pm .025"$) -

$$\frac{0.025"}{12"/\text{ft}} \times \frac{54 \text{ lbs.}}{\text{ft.}} = 0.11 \text{ lbs.}$$

Therefore, to always assure 38 lb. mult, must set up to shear nominal 39.06 lb. mult -

$$38 + .95 + .11 = 39.06$$

Length of billet to be ordered to assure getting 28 mults is 20.25 ft. -

$$\left(\frac{39.06 \text{ lbs./mult} \times 28 \text{ mults/billet}}{54 \text{ lbs./ft.}} = \underline{\underline{20.25 \text{ ft./billet}}} \right)$$

2. Determine length of billet stock to be ordered when cutting to weight such that 28 mults are always obtained.

Weight variation of mult is $\pm .29$ lbs./mult -

$$38 \text{ lbs./mult} \times \pm .0075 \text{ weight variation} = \pm .29 \text{ lbs./mult}$$

Length of billet to be ordered to assure getting 28 mults is 20.36 ft./billet. This is based on worst possible condition (minimum weight) of incoming billet -

$$\left(\frac{28 \text{ mults/billet} \times 38.29 \text{ lbs./mult}}{52.65 \text{ lbs./ft.}} = \underline{\underline{20.36 \text{ ft./bar}}} \right)$$

3. Determine the number of mults that would be obtained if billets came in at maximum weight and + 2" tolerance on length.

Length of billet at maximum length = 20.53 ft. -

$$\left(20.36' + \frac{2''}{12''/\text{ft.}} = 20.53 \text{ ft.} \right)$$

Weight of maximum weight billet = 1136.3 lbs. -

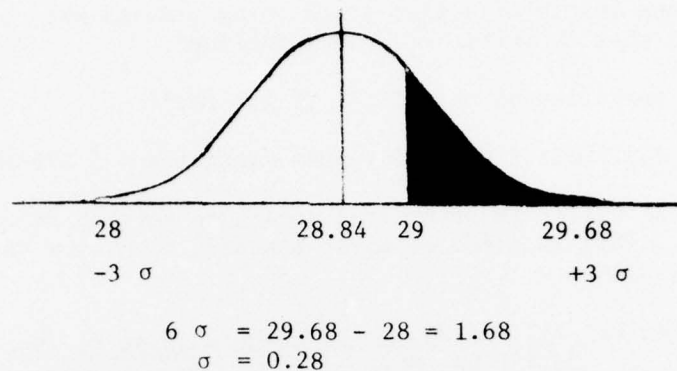
$$\left(20.53 \text{ ft.} \times 55.35 \text{ lbs./ft.} = 1136.3 \text{ lbs./billet} \right)$$

Number of mults in maximum weight billet = 29.68 mults/billet -

$$\frac{1136.3 \text{ lbs./billet}}{38.29 \text{ lbs./mult (nominal)}} = \underline{\underline{29.68 \text{ mults/billet}}}$$

4. Determine the probability of getting 29 mults out of a billet. (Probability of being in shaded area under curve as follows).

Assume normal distribution with upper and lower limits ($+3\sigma$ and -3σ) of 29.68 and 28 mults per billet respectively as shown below:



Probability of 29 mults = $P(t_2) - P(t_1)$.

Where $P(t_2)$ is probability a point will be taken between 28 and 29.68 and where $P(t_1)$ is probability a point will be taken between 28 and 29 and subtraction gives probability of point between 29 and 29.68.

From statistical tables based on normal distribution -

$$\begin{aligned}
 P(t_2) &= .9987 \\
 P(t_1) &= .7160 \\
 P(t_2) - P(t_1) &= .2827
 \end{aligned}$$

or 28% of the time 29 mults/billet will be obtained.

5. Determine difference in scrap between the cut-to-weight and the cut-to-length methods.

Consider 100 billets in cut-to-weight system.
 28 billets will yield 29 mults/billet.
 72 billets will yield 28 mults/billet.

Material used per billet, cut-to-weight -

28 mults/billet X 38 lbs. = 1064 lbs./billet

29 mults/billet X 38 lbs. = 1102 lbs./billet

Material used per 100 billets, cut-to-weight -

(28 billets) (1102 lbs./billet) = 30,856 lbs.

(72 billets) (1064 lbs./billet) = 76,608 lbs.

TOTAL = 107,464 lbs./100 billets

Average cut-to-weight billet will weigh -

20.44' x 54 lbs./ft. = 1,103.76 lbs

Scrap per 100 billets, cut-to-weight -

110,376 lbs. steel purchased - 107,464 lbs. steel used = 2912 lbs.
scrap per 100 billets or 29.1 lbs. scrap/billet.

Average cut-to-length billet will weigh -

20.33' x 54 lbs./ft. = 1,097.82 lbs./billet

Scrap per 100 billets, cut-to-length -

109,782 lbs. steel purchased - 106,400 lbs. steel used = 3,382 lbs.
scrap/100 billets or 33.8 lbs. scrap/billet.

33.8 lbs. - 29.1 lbs. = 4.7 lbs. savings per billet by cutting to weight.

6. Determine savings per month based on 1,000,000 projectiles per month production.

Number of billets required per month, cut-to-weight -

28 x 29y = 1,000,000

$$\frac{x}{y} = \frac{72}{28}$$

x = 25,457 billets giving 28 mults.

y = 9,900 billets giving 29 mults.

35,357 billets per month for cut-to-weight system.

Number of billets required for cut-to-length system per month

$$\frac{1,000,000 \text{ mulds/month}}{28 \text{ mulds/billet}} = 35,714 \text{ billets per month.}$$

Savings per billet used by cut-to-weight method -

$$35,357 \text{ billets used} \times 4.7 \text{ lbs./billet savings} \times \$0.125/\text{lb.} = \$20,772 \text{ savings per month.}$$

also less billets used by cut-to-weight -

$$35,714 - 35,357 = 357 \text{ billets saved/month}$$

$$20.33 \text{ ft.} \times 54 \text{ lbs./ft.} \times 35 \text{ billets} \times \$0.125/\text{lb.} = \$48,990 \text{ savings per month.}$$

Total savings per month by cut-to-weight -

$$\$20,772 + \$48,990 = \$69,762 \text{ savings/month or } \$837,144 \text{ savings/yr.}$$

MATERIAL SAVINGS ASSOCIATED WITH CUT-TO-WEIGHT
METHOD OF BILLET SEPARATION FOR 105 MM M1 FORGING
(MINIMUM OF 33 MULTS PER BILLET,
NOMINAL 24 FT. LENGTH BILLET)

GIVEN:	(A)	Nominal weight of 4 x 4 RCS billet stock	= 54 lbs./ft.
	(B)	Weight variation due to varying cross sectional dimensions of billet stock	= $\pm 2.5\%$
	(C)	Minimum mult weight required	= 38 lbs.
	(D)	Mults per billet (minimum)	= 33
	(E)	Tolerance on billet length	= + 2"
	(F)	Tolerance on mult length	= $\pm .025"$
	(G)	Weight variation in mults cut by weight	= $\pm .75\%$
	(H)	Monthly production for LSAAP	= 1,000,000 projectiles
	(I)	Steel Cost	= \$0.125/lb.

- ASSUMPTIONS: (A) Normal distribution in weight variation of billet stock.
(B) Normal distribution of +2" tolerance on length of billet stock.

CALCULATIONS

1. Determine length of billet stock to be ordered when cutting to length (current practice) such that 33 mults are always obtained.

When cutting to length two variables must be considered to always assure getting 38 lb. mult as follows:

a. Variation in mult weight due to variation in billet weight per unit length (2.5%) $.025 \times 38 \text{ lbs.} = .95 \text{ lbs.}$

b. Variation in mult length ($\pm .025"$) -

$$\left(\frac{0.025"}{12"/\text{ft.}} \times \frac{54 \text{ lbs.}}{\text{ft.}} = 0.11 \text{ lbs.} \right)$$

Therefore, to always assure 38 lb. mult, must set up to shear nominal 39.06 lb. mult

$$38 + .95 + .11 = 39.06$$

Length of billet to be ordered to assure getting 33 mults is 23.87 ft.

$$\left(\frac{39.06 \text{ lbs./mult} \times 33 \text{ mults/billet}}{54 \text{ lbs./ft.}} = \underline{\underline{23.87 \text{ ft./billet}}} \right)$$

2. Determine length of billet stock to be ordered when cutting to weight such that 33 mults are always obtained.

Weight variation of mult is $\pm .29$ lbs./mult -

$$(38 \text{ lbs./mult} \times .0075 \text{ weight variation} = \pm .29 \text{ lbs./mult})$$

Length of billet to be ordered to assure getting 33 mults is 24.00 ft./billet. This is based on worst possible condition (minimum weight) of incoming billet -

$$\left(\frac{33 \text{ mults/billet} \times 38.29 \text{ lbs./mult}}{52.65 \text{ lbs./ft.}} = 24.00 \text{ ft./billet} \right)$$

3. Determine the number of mults that would be obtained if billets came in at maximum weight and + 2" tolerance on length.

Length of billet at maximum length = 24.17 ft. -

$$\left(24.00 + \frac{2''}{12''/\text{ft.}} = 24.17 \text{ ft.} \right)$$

Weight of maximum weight billet = 1337.8 lbs.

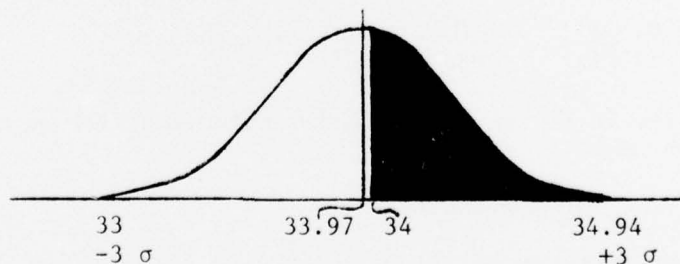
$$(24.17 \text{ ft.} \times 55.35 \text{ lbs./ft.} = 1337.8 \text{ lbs./billet})$$

Number of mults in maximum weight billet = 34.94 mults/billet

$$\left(\frac{1136.3 \text{ lbs./billet}}{38.29 \text{ lbs./mult (nominal)}} = \underline{\underline{34.94 \text{ mults/billet}}} \right)$$

4. Determine the probability of getting 34 mults out of a billet. (Probability of being in shaded area under curve below).

Assume normal distribution with upper and lower limits (+3σ and -3σ) 34.94 and 33 mults per billet respectively as shown below:



$$6 \sigma = 34.94 - 33 = 1.94$$

$$\sigma = 0.32$$

Probability of 34 mults = $P(t_2) - P(t_1)$.

Where $P(t_2)$ is probability a point will be taken between 33 and 34.94 and where $P(t_1)$ is probability a point will be taken between 33 and 34 and subtraction gives probability between 34 and 34.94.

From statistical tables based on normal distribution -

$$P(t_2) = .9987$$

$$P(t_1) = .5360$$

$$P(t_2) - P(t_1) = .4627$$

or 46% of the time 34 mults/billet will be obtained.

5. Determine difference in scrap between the cut-to-weight and the cut-to-length methods.

Consider 100 billets in cut-to-weight system.

46 billets will yield 34 mults/billet.

54 billets will yield 33 mults/billet.

Material used per billet, cut-to-weight -

$$33 \text{ mults/billet} \times 38 \text{ lbs.} = 1254 \text{ lbs./billet}$$

$$34 \text{ mults/billet} \times 38 \text{ lbs.} = 1292 \text{ lbs./billet}$$

Material used per 100 billets, cut-to-weight -

$$(46 \text{ billets}) (1292 \text{ lbs./billet}) = 59,432 \text{ lbs.}$$

$$(54 \text{ billets}) (1254 \text{ lbs./billet}) = 67,716 \text{ lbs.}$$

$$\text{TOTAL} = 127,148 \text{ lbs./100 billets}$$

Average cut-to-weight billet will weigh - $24.08' \times 54 \text{ lbs./ft.} = 1300.32 \text{ lbs.}$

Scrap per 100 billets, cut-to-weight -

$130,032 \text{ lbs. steel purchased} - 127,148 \text{ lbs. steel used} = 2884 \text{ lbs.}$
scrap per 100 billets or $28.8 \text{ lbs. scrap/billet.}$

Average cut-to-length billet will weigh -

$$23.95' \times 54 \text{ lbs./ft.} = 1293.30 \text{ lbs./billet}$$

Scrap per 100 billets, cut-to-length -

129,330 lbs. steel purchased - 125,400 lbs. steel used = 3930
lbs. scrap/100 billets or 39.3 lbs. scrap/billet.

$$39.3 \text{ lbs.} - 28.8 \text{ lbs.} = \underline{\underline{10.5 \text{ lbs. savings per billet by cutting to weight.}}}$$

6. Determine savings per month based on 1,000,000 projectile per month production.

Number of billets required per month, cut-to-weight -

$$33x + 34y = 1,000,000$$

$$\frac{x}{y} = \frac{54}{46}$$

$x = 16,139$ billets giving 33 mults.

$y = 13,748$ billets giving 34 mults.

29,887 billets per month for cut-to-weight system.

Number of billets required for cut-to-length system per month -

$$\frac{1,000,000 \text{ mults/month}}{33 \text{ mults/billet}} = 30,303 \text{ billets per month}$$

Savings per billet used by cut-to-weight method -

29,887 billets used x 10.5 lbs./billet savings x \$0.125 lb. =
\$39,226 savings per month.

also less billets used by cut-to-weight -

$$30,303 - 29,887 = 416 \text{ billets saved/month}$$

23.95 ft. x 54 lbs./ft. x 416 billets x \$0.125/lb. = \$67,252
savings per month.

Total savings per month by cut-to-weight -

\$39,226 + \$67,252 = \$106,478 savings/month or \$1,277,736
savings/yr.

MATERIAL SAVINGS ASSOCIATED WITH CUT-TO-WEIGHT
METHOD OF BILLET SEPARATION FOR 155 MM M483
(MINIMUM OF 27 MULTS PER BILLET,
NOMINAL 24 FT. LENGTH BILLET)

GIVEN:	(A)	Nominal weight 5¼ x 5¼ RCS billet stock	= 93 lb
	(B)	Weight variation due to varying cross sectional dimensions of billet stock	= \pm 2.5%
	(C)	Minimum mult weight required	= 80 lb
	(D)	Mults per billet (minimum)	= 27
	(E)	Tolerance on billet length	= + 2"
	(F)	Tolerance on mult length	= \pm .025"
	(G)	Weight variation in mults cut by weight	= \pm .75%
	(H)	Monthly production MSAAP	= 120,000 projects
	(I)	Steel Cost	= \$0.17/lb

- ASSUMPTIONS:
- (A) Normal distribution in weight variation of billet stock.
 - (B) Normal distribution of + 2" tolerance in length of billet stock.

CALCULATIONS

1. Determine length of billet stock to be ordered when cutting to length (current practice) such that 27 mults are always obtained.

When cutting to length two variables must be considered to assure getting 80 lb. mult as follows:

a. Variation in mult weight due to variation in billet weight
unit length (2.5%) - $.025 \times 80 \text{ lbs.} = 2 \text{ lbs.}$

b. Variation in mult length ($\pm .025"$) -

$$\frac{0.025"}{12"/\text{ft.}} \times \frac{93 \text{ lbs.}}{\text{ft.}} = 0.19 \text{ lbs.}$$

Therefore, to always assure 80 lb. mult, must set up to shear nominal 82.19 lb. mult

$$(80 + 2 + .19 = 82.19)$$

Length of billet to be ordered to assure getting 27 mults is
ft. -

$$\left(\frac{82.19 \text{ lbs./mult} \times 27 \text{ mults/billet}}{93 \text{ lbs./ft.}} = 23.86 \text{ ft./billet} \right)$$

2. Determine length of billet stock to be ordered when cutting to weight such that 27 mults are always obtained.

Weight variation of mult is $\pm .6$ lbs./mult

$$\left(80 \text{ lbs./mult} \times \pm .0075 \text{ weight variation} = \pm .6 \text{ lbs./mult} \right)$$

Length of billet to be ordered to assure getting 27 mults is 24.00 ft./billet. This is based on worst possible condition (minimum weight) of incoming billet -

$$\left(\frac{27 \text{ mults/billet} \times 80.6 \text{ lbs./mult}}{90.675 \text{ lbs./ft.}} = \underline{24.00 \text{ ft./bar}} \right)$$

3. Determine the number of mults that would be obtained if billets came in at maximum weight and + 2" tolerance on length.

Length of billet at maximum length = 24.17 ft.

$$\left(24.00 + \frac{2''}{12''/\text{ft.}} = 24.17 \text{ ft.} \right)$$

Weight of maximum weight billet = 2304 lbs. -

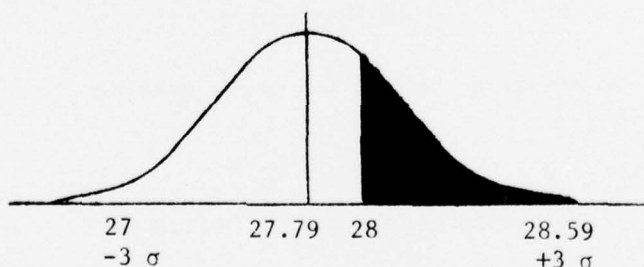
$$\left(24.17 \text{ ft.} \times 95.325 \text{ lbs./ft.} = 2304 \text{ lbs./billet} \right)$$

Number of mults in maximum weight billet = 28.59 mults/billet

$$\left(\frac{2304 \text{ lbs./billet}}{80.6 \text{ lbs./mult (nominal)}} = \underline{28.59 \text{ mults/billet}} \right)$$

4. Determine the probability of getting 28 mults out of a billet. (Probability of being in shaded area under curve below).

Assume normal distribution with upper and lower limits (+3 σ and -3 σ) of 28.59 and 27 mults per billet respectively as shown below:



$$\begin{aligned} 6 \sigma &= 28.59 - 27 = 1.59 \\ \sigma &= .26 \end{aligned}$$

Probability of 28 mults = P (t2) - P (t1).

Where $P(t_2)$ is probability a point will be taken between 27 and 28.59 and where $P(t_1)$ is probability a point will be taken between 27 and 28 and subtraction gives probability of point between 28 and 28.59.

From statistical tables based on normal distribution -

$$\begin{aligned}P(t_2) &= .9987 \\P(t_1) &= .7852 \\P(t_2) - P(t_1) &= .2135\end{aligned}$$

Or 21% of the time 29 mults/billet will be obtained.

5. Determine difference in scrap between the cut-to-weight and the cut-to-length methods.

Consider 100 billets in cut-to-weight system.
21 billets will yield 28 mults/billet.
79 billets will yield 27 mults/billet.

Material used per billet, cut-to-weight -

$$\begin{aligned}27 \text{ mults/billet} \times 80 \text{ lbs.} &= 2160 \text{ lbs./billet} \\28 \text{ mults/billet} \times 80 \text{ lbs.} &= 2240 \text{ lbs./billet}\end{aligned}$$

Material used per 100 billets, cut-to-weight -

$$\begin{aligned}(21 \text{ billets}) (2240 \text{ lbs./billet}) &= 47,040 \text{ lbs.} \\(80 \text{ billets}) (2160 \text{ lbs./billet}) &= 170,640 \text{ lbs.} \\ \text{TOTAL} &= 217,680 \text{ lbs.}\end{aligned}$$

Average cut-to-weight billet will weigh - $24.08' \times 93 \text{ lbs./ft.} = 2,239 \text{ lbs.}$

Scrap per 100 billets, cut-to-weight -

$223,900 \text{ lbs. steel purchased} - 217,680 \text{ lbs. steel used} = 6620 \text{ lbs.}$
scrap per 100 billets or 66.2 lbs. scrap/billet.

Average cut-to-length billet will weigh -

$$23.94' \times 93 \text{ lbs./ft.} = 2226.42 \text{ lbs./billet}$$

Scrap used per 100 billets, cut-to-length -

222,642 lbs. steel purchased - 216,000 lbs. steel used = 6642 lbs. scrap/100 billets or 66.4 lbs. scrap/billet.

$$66.4 \text{ lbs.} - 62.2 \text{ lbs.} = \underline{\underline{4.2 \text{ lbs. savings per billet by cutting to weight.}}}$$

6. Determine savings per month based on 120,000 projectiles per month production.

Number of billets required per month, cut-to-weight -

$$27x + 28y = 120,000$$

$$\frac{x}{y} = \frac{79}{21}$$

$$x = 3472 \text{ billets giving 28 mults.}$$

$$y = \underline{923} \text{ billets giving 29 mults.}$$

4395 billets per month for cut-to-weight system.

Number of billets required for cut-to-length system per month -

$$\frac{120,000 \text{ mults/month}}{27 \text{ mults/billet}} = 4444 \text{ billets per month}$$

Savings per billet used by cut-to-weight method -

$$4395 \text{ billets used} \times 4.2 \text{ lbs./billet savings} \times \$0.17 \text{ lbs.} = \$3,138 \text{ savings per month -}$$

also less billets used by cut-to-weight -

$$4444 - 4395 = 49 \text{ billets saved/month}$$

$$23.94 \text{ ft.} \times 93 \text{ lbs./ft.} \times 49 \text{ billets} \times \$0.17 \text{ lb.} = \$18,546 \text{ savings per month.}$$

Total Savings per month by cut-to-weight -

$$\$3,138 + \$18,546 = \$21,684 \text{ savings/month or } \$260,208 \text{ savings/year.}$$

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$\frac{0.025}{12''/f}$

Therefore
82.19 lb.

(80 +

Length

ft. -

(82.19

